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(54) **CONTROL DEVICE FOR MAGNETIC FIELD GENERATOR, TEST APPARATUS, AND MAGNETIC FIELD CONTROL METHOD**

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(57)   **ABSTRACT**

A control device controls a magnetic field generated by a magnetic field generator, and includes a magnetic field controller that controls the magnetic field generator based on a detected value by a magnetic field sensor. The magnetic field controller receives a command value generated by the magnetic field generator, and the detected value. The magnetic field controller generates an error signal based on an error between the command value and the detected value and outputs to the magnetic field generator a control signal amplified by a control gain against the error. The control gain includes: a first gain that becomes smaller as a frequency of the error signal gets higher; and a second gain that gets larger as an amplitude of the error signal gets larger.
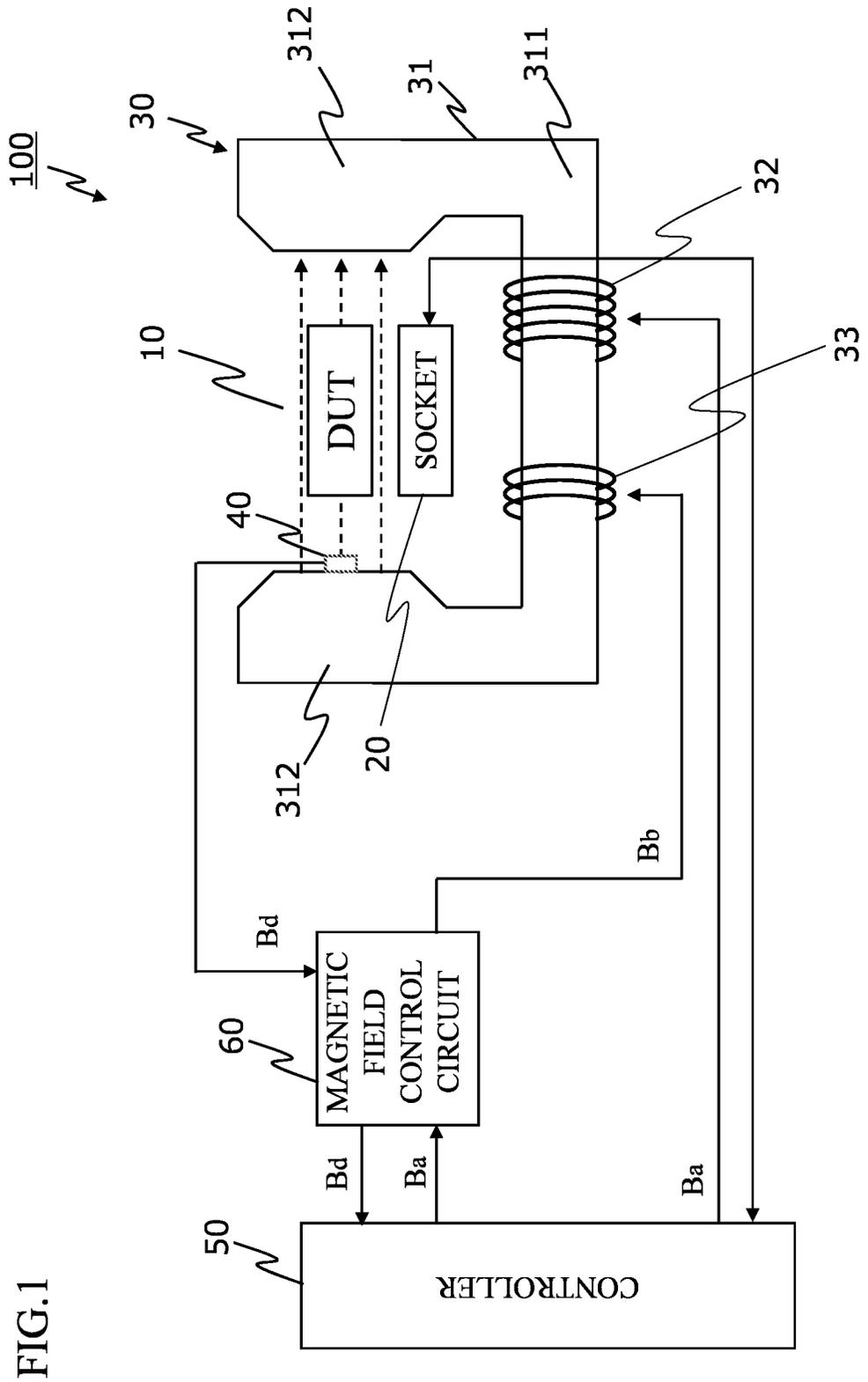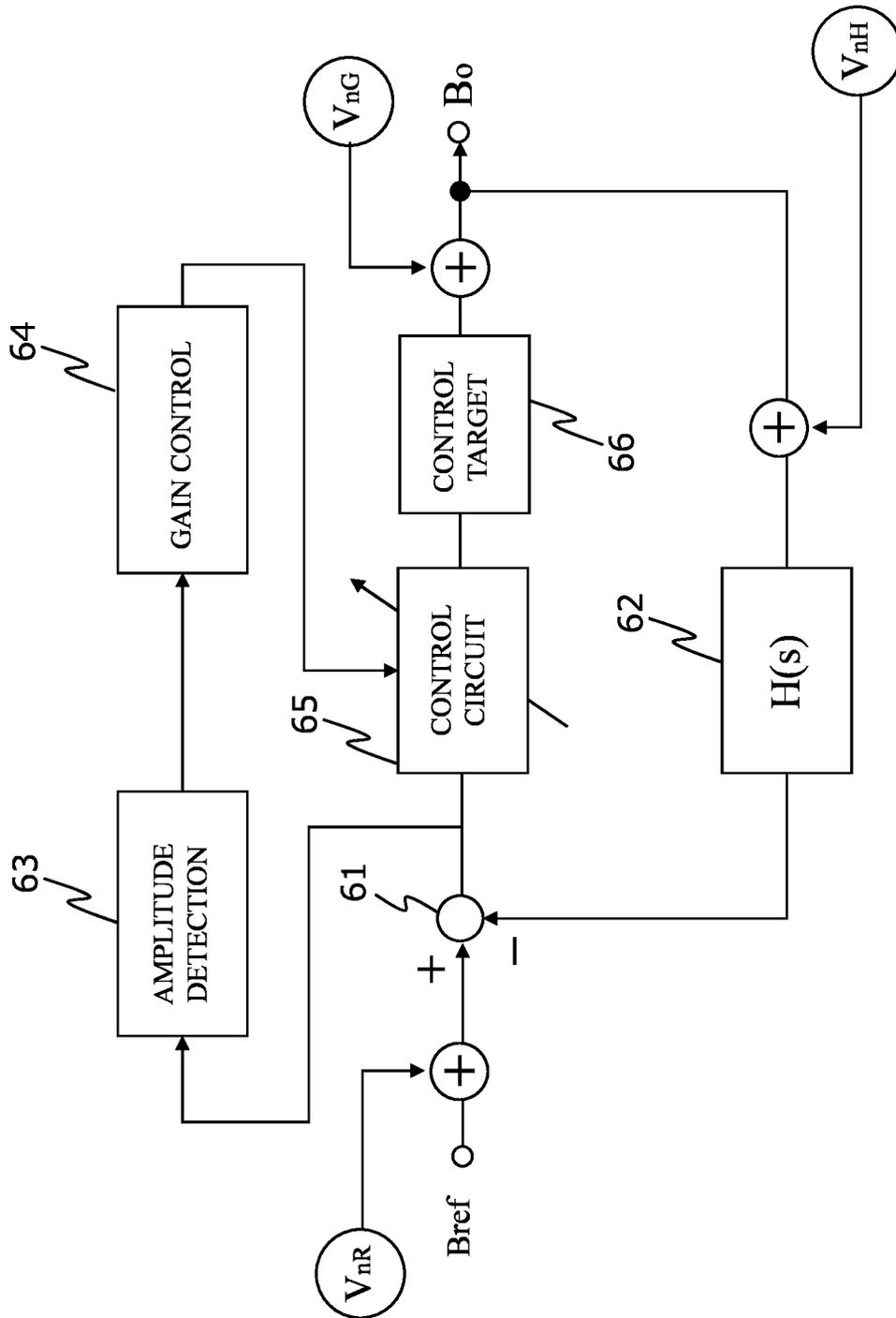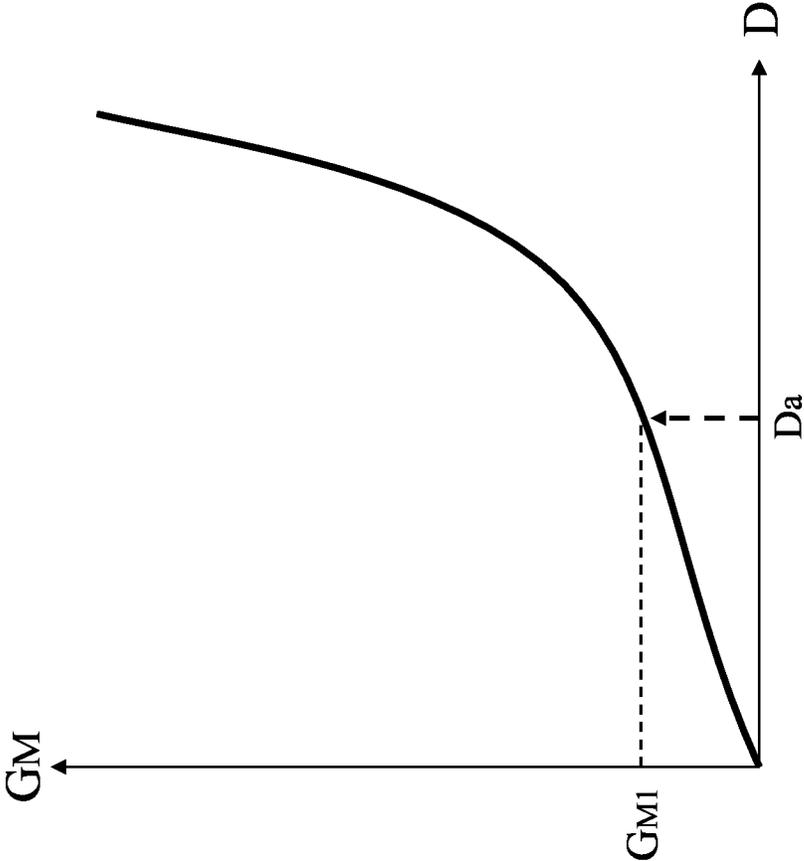
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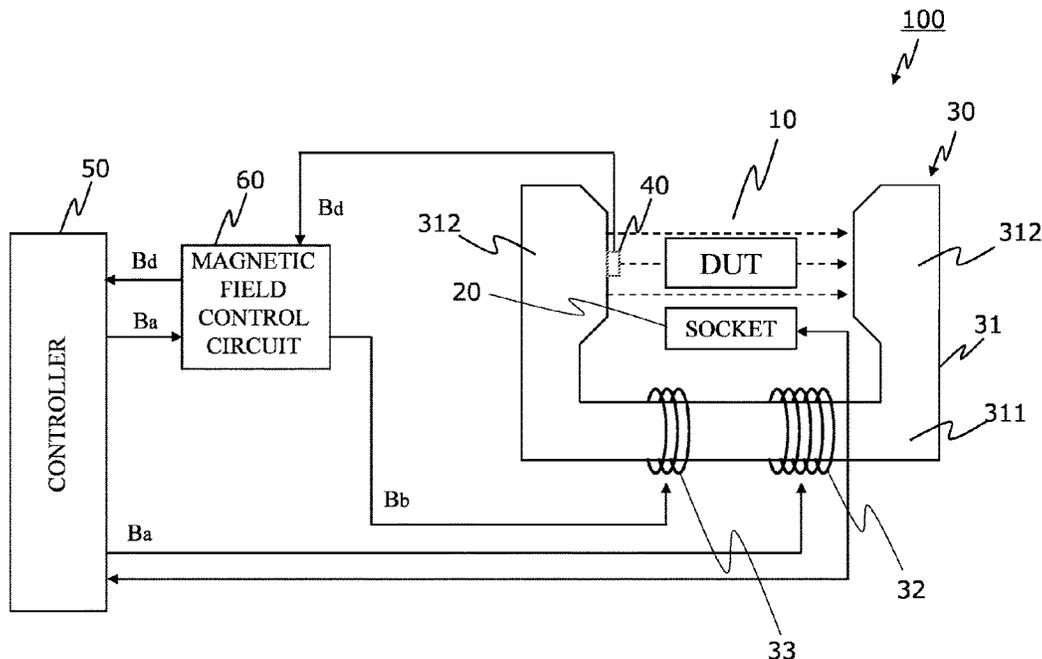
FIG.1

FIG.2

FIG.3
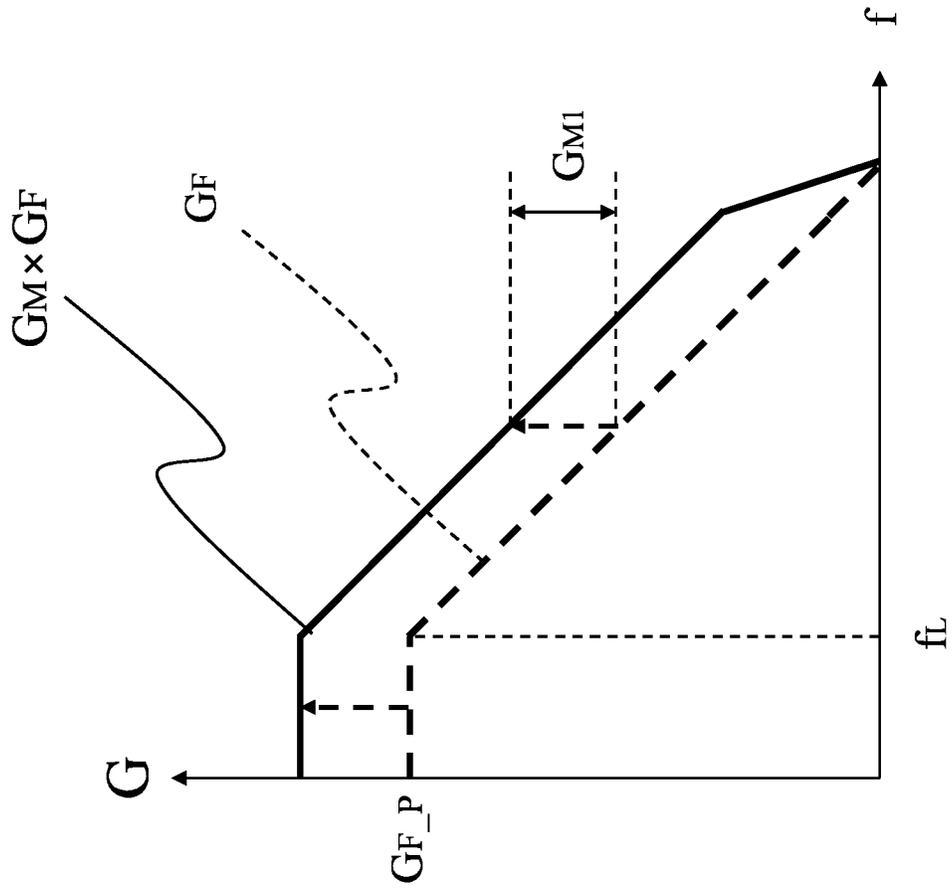
FIG.4

FIG.5A

FIG.5B

FIG.5C

FIG.5D

CONTROL DEVICE FOR MAGNETIC FIELD GENERATOR, TEST APPARATUS, AND MAGNETIC FIELD CONTROL METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority from Japanese Patent Application No. 2021-021090 filed on Feb. 12, 2021, the contents of which are incorporated herein by reference in their entirety.

BACKGROUND

Technical Field

The present invention is related to a control device for a magnetic field generator, a test apparatus, and a magnetic field control method.
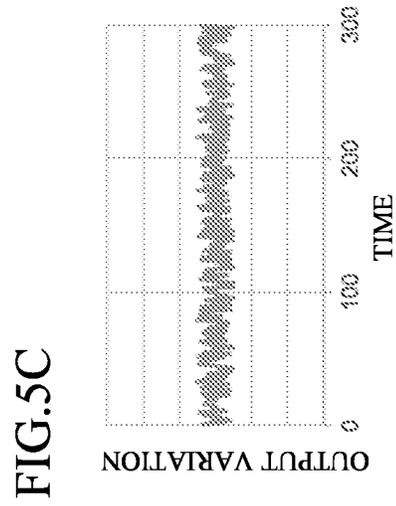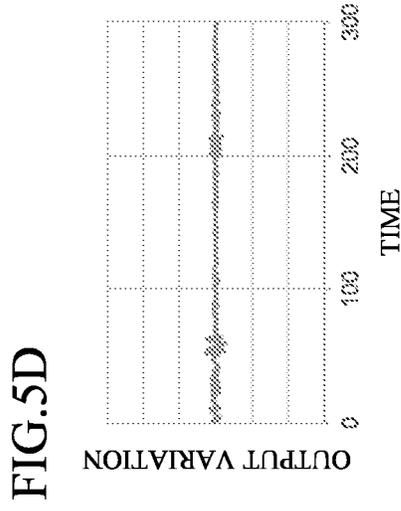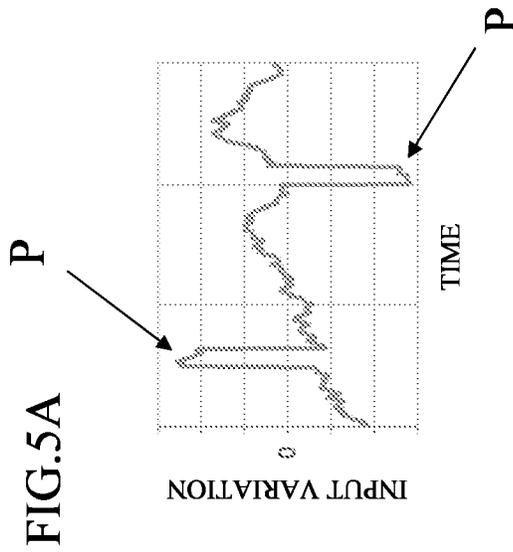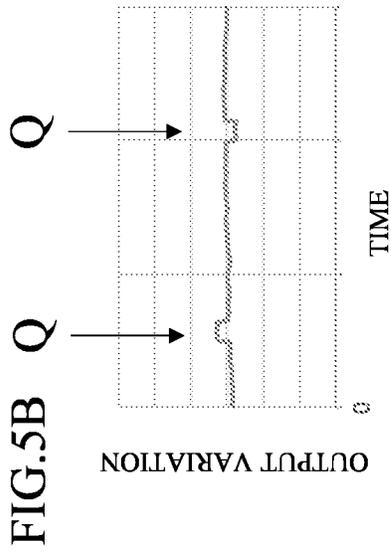
DESCRIPTION OF RELATED ART

A PID controller that automatically sets PID parameters is known (for example, refer to Patent Document 1). In the PID controller, the auto-tuning section gradually increases the proportional gain Kp of the PID controller while the PID controller is in the P-control state and the target value input is kept constant. As Kp is increased, oscillations are generated in the deviation. The FFT analyzer analyzes the deviation and detects the natural oscillation frequency included in the deviation from the peak frequency. The filter removes noise components with frequencies higher than the natural oscillation frequency and outputs them to the RMS processing unit. The RMS processing unit calculates an effective value of each cycle of the oscillation of the deviation. The RMS processing unit sends a trigger signal to the auto-tuning unit to lower the value of Kp in the PID control unit when detecting that the value is increasing for multiple consecutive cycles. When the auto-tuning section receives the trigger signal, the PID parameters are determined from the proportional gain Kpc and the period Tc of the natural vibration at that time.

PATENT DOCUMENT

[Patent Document 1] Japanese Patent Application Publication 2008-044305

In the PID controller described in Patent Document 1, the response characteristics of the control system cannot be dynamically optimized when the range of speed demand of feedback control is wide.

SUMMARY

One or more embodiments of the present invention provide a control device for a magnetic field generator, a test apparatus, and a magnetic field control method in which the response characteristics of the control system are optimized.

[1] A control device according to one or more embodiments of the present invention comprises: a magnetic field control circuit (i.e., a magnetic field controller) that controls the magnetic field generator based on a detected value of a magnetic field sensor for detecting the magnetic field, wherein a command value of the magnetic field to be generated by the magnetic field generator is input to the magnetic field control circuit, the detected value of a magnetic field sensor is fed back and input to the magnetic field

control circuit, the magnetic field control circuit generates an error signal in accordance with an error between the command value and the detected value and outputs a control signal amplified by a control gain against the error to the magnetic field generator, the control gain includes a first gain and a second gain, the first gain has a characteristic that the higher a frequency of the error signal, the smaller the gain, and the second gain has a characteristic that the larger amplitude of the error signal, the larger the gain.

[2] In the above-mentioned embodiments, the second gain may be set in accordance with command value response required for variation in the command value, output value response required for variation in the output of the magnetic field generator, and a detected value response required for variation in the detection value of the magnetic sensor.

[3] In the above-mentioned embodiments, the second gain may have a characteristic that the gain increases continuously with increasing the amplitude.

[4] A test apparatus according to one or more embodiments of the present invention comprises: a magnetic field generator that includes a coil and a core, and outputs a magnetic field to the electronic component under test; a magnetic field sensor that detects the magnetic field; and a magnetic field control circuit that controls the magnetic field generator based on a detected value of a magnetic field sensor for detecting the magnetic field; wherein a command value of the magnetic field to be generated by the magnetic field generator is input to the magnetic field control circuit, the detected value of a magnetic field sensor is fed back and input to the magnetic field control circuit, the magnetic field control circuit generates an error signal in accordance with an error between the command value and the detected value and outputs a control signal amplified by a control gain against the error to the magnetic field generator, the control gain includes a first gain and a second gain, the first gain has a characteristic that the higher a frequency of the error signal, the smaller the gain, and the second gain has a characteristic that the larger amplitude of the error signal, the larger the gain.

[5] A magnetic field control method according to one or more embodiments of the present invention comprises: a step of obtaining, by a feedback control, a detected value of a magnetic field sensor for detecting the magnetic field; a step of obtaining a command value of the magnetic field generated by a magnetic field generator; a step of generating an error signal in accordance with an error between the command value and the detected value; and a step of outputting a control signal amplified by a control gain against the error to the magnetic field generator, wherein the control gain includes a first gain and a second gain, the first gain has a characteristic that the higher a frequency of the error signal, the smaller the gain, and the second gain has a characteristic that the larger amplitude of the error signal, the larger the gain.

According to one or more embodiments of the present invention, the response characteristics of the control system can be optimized because the optimal control gain is set over a wide speed range for the speed demand of the feedback control by being sensitive to both the amplitude and frequency components of the control error.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram of the test apparatus.
FIG. 2 is a block diagram of the test apparatus in FIG. 1.
FIG. 3 is a graph showing the characteristics of the gain against to the amplitude of the error signal.

FIG. **4** shows the gain characteristics of the control gain set in the magnetic field control circuit.

FIGS. **5A-5D** are graphs illustrating the relationship between input variation and output variation in the test apparatus of FIG. **1**.

DETAILED DESCRIPTION

Hereinafter, embodiments of the present invention will be described with reference to the drawings. FIG. **1** is a block diagram of the test apparatus.

The test apparatus shown in FIG. **1** applies a magnetic field to the electronic component under test (DUT) **10** and tests (inspects) whether the DUT operates properly in this state. The DUT **10** is an object to be tested by the test apparatus according to one or more embodiments, for example, a sensor such as a current sensor or a magnetic sensor.

As shown in FIG. **1**, a test apparatus **100** includes a socket **20**, a magnetic field generator **30**, a magnetic field sensor **40**, a controller **50**, and a magnetic field control circuit (i.e., a magnetic field controller) **60**. The socket **20** contacts and electrically connects with the DUT **10** while holding the DUT **10**. A pin is provided on the top surface of the socket **20** for contacting the DUT **10**. The socket **20** has signal lines electrically connected to the pins. The socket **20** is connected to the controller **50** via a cable not shown in the drawing. Electrical signals from the controller **50** are sent to the DUT **10** via the socket **20** with the DUT **10** connected to the socket **20**, and the DUT **10** is tested based on the signals output from the DUT **10**.

The magnetic field generator **30** is an electromagnet and has a core **31**, a main coil **32**, and a correction coil **33**. The core **31** is a member that strengthens the magnetic flux generated by the main coil **32** and the correction coil **33**, and passes the closed loop (magnetic circuit) formed by the magnetic flux through the DUT **10**.

The core **31** has a main body **311** around which the main coil **32** and the correction coil **33** are wound, and an extension **312** extending from the main body **311** toward the DUT **10**. The main body **311** and the extension **312** are integrated. The main body **311** is formed in the shape of a column. The extension **312** extends from both ends of the main body **311** so as to approach the sides of the DUT **10**. A magnetic field is generated from the end of one extension **312** toward the end of the other extension **312**, and the DUT **10** is placed in a magnetic circuit.

The main coil **32** is wound around the main body **311**. When a current flows through the main coil **32** under the control of the controller **50**, a magnetic flux is generated, and the magnetic flux passes in a closed loop containing the core **31** and the DUT **10**.

The correction coil **33** is wound on the main body **311**. The number of turns of the correction coil **33** is less than the number of turns of the main coil **32**. The correction coil **33** is a coil for correcting the magnetic field generated by the magnetic field generator **30**. When current flows to the correction coil **33** while current is flowing in the main coil **32** and a magnetic field is being generated, the magnetic field generated by the correction coil **33** is added to the magnetic field generated by the main coil **32**. The magnetic field generated by the correction coil **33** is smaller than the magnetic field generated by the main coil **32**. By controlling the current flowing in the main coil **32**, the magnetic field generated by the magnetic field generator **30** is adjusted to a larger value, and by controlling the current flowing in the

correction coil **33**, the magnetic field generated by the magnetic field generator **30** is adjusted to a smaller value.

The magnetic field sensor **40** detects the magnetic field (magnetic flux) generated by the magnetic field generator **30**. The magnetic field sensor **40** is located in the magnetic circuit. The detected value of the magnetic field sensor **40** is output to the magnetic field control circuit **60**.

The controller **50** controls the current flowing in the main coil **32** and the correction coil **33**. The controller **50** has an arithmetic unit such as a CPU or MPU, and memory such as ROM and RAM. The controller **50** sets the magnetic field to be applied to the DUT based on an external command or operation by the user, and outputs the magnetic field command value (Ba) to the main coil **32** and the magnetic field control circuit **60** for generating the set magnetic field. The current to generate the magnetic field command value (Ba) flows to the main coil **32**. The controller **50** obtains the detected value (Bd) of the magnetic field sensor **40** via the magnetic field control circuit **60**. When the set magnetic field is to be changed, the controller **50** calculates the magnetic field command value (Ba) so that the detected value becomes the set magnetic field after the change.

The magnetic field control circuit **60** is a control circuit that comprises, for example, a microcontroller, and controls the magnetic field generator **30** based on the detected values of the magnetic field sensor **40**. The device including the magnetic field control circuit **60** corresponds to the control device of one or more embodiments of the present invention. The detected value (Bd) of the magnetic field sensor **40** is fed back and input to the magnetic field control circuit **60**. The magnetic field command value (Ba) is input to the magnetic field control circuit **60** from the controller **50**. The magnetic field control circuit **60** detects the error between the magnetic field command value (Ba) and the detected value (Bd) by calculating the difference between the magnetic field command value (Ba) and the detected value (Bd). The magnetic field control circuit **60** generates a signal according to the detected error. Specifically, the magnetic field control circuit **60** generates a signal that includes the magnetic field command value (Bb) to be generated by the correction coil **33** so that the detected value (Bd) matches the magnetic field command value. For example, if the detected value is lower than the set magnetic field (set magnetic flux), the command value (Bb) of the magnetic field to be generated by the correction coil **33** is calculated so that the magnetic field of the magnetic field generator **30** is increased, and the calculated magnetic field command value (Bb) is output to the correction coil **33**. The controller **50** and the magnetic field control circuit **60** control the main coil **32** and the correction coil **33** by current control or voltage control.

Next, the system control in the test apparatus **100** is described with reference to FIG. **2**. The system control in the test apparatus **100** includes feed-forward and feedback elements. The system control has a calculation unit **61**, control elements **62** to **65**, and a control target **66**. The signal containing the magnetic field command value (Ba) that is input from the controller **50** to the magnetic field control circuit **60** corresponds to the reference input signal (Bref) of the system control. The arithmetic processing by the calculation unit **61** and the control process by the control elements **63** to **65**, which are described in detail below, are executed in the magnetic field control circuit **60**. The control process including control element **62** is also executed by returning the detected value of the magnetic field sensor to the magnetic field control circuit **60**.

The calculation unit **61** calculates the difference (ΔV) between the magnetic field command value (Ba) contained in the reference input signal and the detected value. The detected value is the value converted by the control element **62**. The difference (ΔV) corresponds to the error between the command value and the detected value. Then, the calculation unit **61** outputs the error signal including the difference (ΔV) to the control elements **63** and **65**. In this way, the calculation unit **61** generates an error signal according to the error between the command value and the detected value, and outputs the error signal to the control elements **63** and **65**.

The control element **62** is the element that converts the controlled quantity into a signal that can be compared to a reference input signal, and corresponds to the magnetic field sensor **40**. The controlled quantity is the magnetic field generated by the magnetic field generator **30**. The control element **62** is a feedback element and is represented by the transfer function ($H(s)$).

The control element **63** detects the amplitude component of the error signal (amplitude detection). The amplitude component of the error signal is a transient control error and is represented by the peak, integral, average, or RMS value of the error signal per predetermined time. The control element **64** determines the gain (G_M) to change the response characteristics of the control system against to the transient control error (gain control). The control element **64** stores predetermined gain characteristics in a map. The characteristics of the gain, which is set by the control element **64**, are represented by the graph shown in FIG. **3**. In FIG. **3**, the horizontal axis indicates the amplitude of the error signal (D), and the vertical axis indicates the magnitude of the gain (G_M). The gain (G_M) of the control element **64** has a characteristic that the larger the amplitude (D) of the error signal, the larger the gain (G_M). The gain (G_M) has the characteristic that the gain increases continuously with increasing the amplitude (D) of the error signal. The control element **64** then sets a small gain (G_M) when the amplitude of the error signal is small, and sets a large gain (G_M) when the amplitude of the error signal is large. The gain characteristic shown in FIG. **3** is only one example. The gain (G_M) characteristic may be a characteristic that increases proportionally to the amplitude (D) of the error signal. The gain (G_M) may also have a characteristic such that the larger the amplitude (D) of the error signal, the larger the gain (GM) in some range of amplitudes. For example, if the amplitude (D) of the error signal is less than or equal to a predetermined low amplitude side threshold, the magnitude of the gain (G_M) is the first predetermined value, and if the amplitude (D) of the error signal is greater than the low amplitude side threshold and less than the predetermined high amplitude side threshold, the larger the amplitude (D) of the error signal, the larger the gain (G_M). When the amplitude (D) of the error signal is greater than the threshold on the high amplitude side, the magnitude of the gain (G_M) may be characterized as the second predetermined value (>the first predetermined value). The gain (GM) may also have a characteristic such that the magnitude of the gain remains at a constant value in a part of the amplitude range. The control element **64** outputs the set gain (GM) to the control element **65**. The control element **63** and the control element **64** correspond to the feed-forward elements.

The control element **65** generates a control signal by increasing the error with the control gain ($G(s)$), and outputs the generated control signal to the control target **66**. The control element **65** generates the control signal in the following manner. The control element **65** performs a fil-

tering process on the error signal to identify the frequency components included in the error signal that have unique frequency response characteristics. The control element **65** determines a gain (G_F) for the identified frequency component. The gain (G_F) is a gain for changing the response characteristics of the control system against to a stationary control error. The control element **65** stores the predetermined gain characteristics in a map. The characteristics of the gain (G_F) set by the control element **65** are represented by the graph shown in FIG. **4**. In FIG. **4**, the horizontal axis represents the frequency (f) of the error signal. The vertical axis represents the magnitude of the gain. The dotted line graph in FIG. **4** shows the characteristics of the gain (G_F). The gain (G_F) has a characteristic that the higher the frequency of the error signal, the smaller the magnitude of the gain. In the example of FIG. **4**, when the frequency of the error signal is below the low frequency side threshold (f_L), the magnitude of gain (G_F) becomes the maximum gain (G_{F_P}). When the frequency of the error signal is higher than the low frequency side threshold (f_L) and lower than the high frequency side threshold (GO, the magnitude of gain (G_F) becomes proportional to the increase in frequency When the error signal frequency is higher than the low frequency side threshold (f_L) and lower than the high frequency side threshold, the magnitude of the gain (G_F) becomes smaller in proportion to the increase in frequency.

The gain (G_F) may have a characteristic that the magnitude of the gain (G_F) decreases as the frequency increases in some range of frequencies, and does not necessarily have to be a linear function characteristic as shown in FIG. **4**. The gain (G_F) may have a characteristic such that the magnitude of the gain remains at a constant value in a part of the frequency range.

The control element **65** determines the control gain ($G_M \times G_F$) by adding the gain (G_M) determined by the control element **64** to the gain (G_F) determined by referring to the map. In other words, the control gain ($G_M \times G_F$) includes the gain (G_M) and the gain (G_F). The solid line graph in FIG. **4** shows the characteristics of the control gain ($G_M \times G_F$). For example, when the amplitude of the error signal is Da, the control element **64** determines the magnitude of the gain (G_M) to G_{M1}. The control element **65** adds the gain (G_{M1}) for the oscillation component to the gain (G_F) for the frequency component of the error signal. In FIG. **4**, when the vertical axis is displayed in logarithmic form, the control gain is the gain characteristic shifted by the gain (G_{M1}) so that the gain becomes larger in relation to the gain (G_F). As a result, the control gain becomes larger by a gain shift of the gain (G_{M1}). For example, in the example of FIGS. **3** and **4**, if the amplitude of the error signal is larger than Da, the gain (G_M) is larger than G_{M1}, and therefore the amount of shift in control gains also be larger.

The control element **65** amplifies the error signal with the control gain ($G_M \times G_F$). The control element **65** converts the command value (command value after amplification by the control gain) contained in the amplified error signal into a control signal that can be controlled by the control target **66** and outputs the converted signal to the control target **66**. The control target **66**, which corresponds to the magnetic field generator **30**, generates a magnetic field based on the control signal.

Next, the variation factors (noise factors) that affect the system control and the required responsiveness to different variation will be explained with reference to FIG. **2**. In FIG. **2**, V_{nG}, V_{nH}, and V_{nR} represent variation (noise) added to the system control, and V_{nG} represents variation in the control system caused by factors external to the test apparatus **100**,

such as vibrations applied to the test apparatus **100** and magnetic changes in the core. In the following explanation, the variation factor for which a high response speed is required for variation suppression is V_{nG} (high speed), and the variation factor for which a low response speed is required for variation suppression is V_{nR} (low speed). The variation factor that requires a response speed lower than that of the variation factor (V_{nG}) and higher than that of the variation factor (V_{nR}) in order to suppress variation is designated as V_{nH}. However, the size of the response speed required to suppress V_{nG}, V_{nH}, and V_{nR} may vary as required depending on the system control setting conditions, operating conditions, or environment. In other words, the order of the response speed to suppress the variation factors (V_{nG}, V_{nH}, V_{nR}) is not limited to the order of "high speed, medium speed, low speed" as shown in the following example, but may be "high speed, low speed, medium speed", "medium speed, high speed, low speed", or "low speed, medium speed, high speed", etc. In this form of system control, the feed-forward gain (G_M) is increased to speed up the feedback speed of loop control by increasing the control gain and suppressing variation. On the other hand, if the control gain is small, it takes a long time to return the output value of the control target **66** to the command value of the reference input signal when the output value of the control target **66** fluctuates due to fluctuations caused by V_{nG}. In the system control in one or more embodiments, the variation caused by V_{nG} is detected from the amplitude component of the error signal, and the gain is increased by the gain control of the control element **64**. Furthermore, during testing, when the magnetic field setting is changed by an external command, the generated magnetic field of the magnetic field generator **30** can be made to follow the change in the magnetic field setting at a high speed, and the speed of the magnetic field setting can also be improved.

V_{nR} represents the noise contained in the reference input signal, and represents variation caused by internal noise of the arithmetic unit that calculates the command value (reference value), etc. V_{nR} requires a low response speed (low speed) compared to other variations factors (V_{nH} and V_{nG}). When the command value fluctuates due to internal factors such as internal noise of the arithmetic unit, the command value fluctuates at a high speed. Therefore, when the feed-forward gain (G_M) is lowered, the control gain is lowered, and the feedback speed of the loop control is slowed down, the command value fluctuation will be absorbed. On the other hand, when the feedback speed of the loop control is fast, the gain setting will change in accordance with the variation of the command value, and the command of the control signal will not be stable. In other words, in one or more embodiments, when the command value of the error signal fluctuates due to internal factors, the control gain is set so that the fluctuation is absorbed.

V_{nH} represents the noise included in the detected value of the magnetic field sensor **40**, for example, the variation caused by the noise inside the sensor. V_{nH} requires a lower response speed (medium speed) compared to other variation factors (V_{nG}). Therefore, as in the case of low speed, the system control of one or more embodiments absorbs the variation of the detected value of the magnetic field sensor **40** by lowering the gain (GM) of the feed-forward, lowering the control gain, and slowing down the feedback speed of the loop control.

Thus, the gain (G_M) set in this system control of one or more embodiments is set according to the command value response required for the command value of the reference value signal (low speed), the output value response required

for the output variation of the magnetic field generator **30** (high speed), and the detection value response required for the variation of the detection value of the magnetic field sensor **40** (medium speed). This makes it possible to achieve both high-speed control to follow changes in the magnetic field setting at high speed and internal noise suppression to absorb variation in the command value/detected value caused by internal noise.

FIGS. **5A**-**5D** illustrate the input and output variations to the system control in the test apparatus **100**. FIG. **5A** shows the input variation. The input variation shown in FIG. **5A** includes noise from external factors and noise from internal factors. The external factor is represented by the arrow P. The effect of the noise of the external factor causes the command value contained in the reference signal to change in a pulsed manner. The input variation other than the arrow P is the noise of internal factors. The graph shown in FIG. **5B** represents the output variation when only low-speed control is performed among high-speed and low-speed control. The high speed control represents the loop control with high response speed by increasing the control gain. In the system control in the test apparatus **100**, the control that increases the feed-forward gain (G_M) corresponds to the high-speed control. The low-speed control represents the loop control with low response speed by lowering the control gain. In the system control in the test apparatus **100**, the control that lowers the gain (G_M) of feedforward and/or the control under the loop characteristic of the gain (G_F) of feedback corresponds to the low-speed control. As shown in FIG. **5B**, when only low-speed control is performed, the variation due to noise from internal factors is reduced, but the variation due to noise from external factors is not sufficiently suppressed (refereeing to the arrow Q).

The graph shown in FIG. **5C** shows the output variation when only high-speed control is performed among high-speed and low-speed control. When only high speed control is performed, the variation caused by noise from external factors becomes smaller, but the variation caused by noise from internal factors cannot be suppressed.

The graph shown in FIG. **5D** shows the output variation of the system control in the test apparatus **100** when both high-speed and low-speed control are performed. When both high-speed control and low-speed control are performed, both the variation caused by internal noise and external noise can be suppressed.

As explained above, the control device for the magnetic field generator **30** of one or more embodiments includes the magnetic field control circuit **60** that controls the magnetic field generator **30** based on the detected value of the magnetic field sensor **40**. The command value of the magnetic field to be generated by the magnetic field generator **30** is input to the magnetic field control circuit **60**. The detected value of the magnetic field sensor **40** fed back and input to the magnetic field control circuit **60**. The magnetic field control circuit **60** generates the error signal according to the error between the command value and the detected value, and outputs a control signal amplified by a control gain against the error to the magnetic field generator **30**. The control gain includes the gain G_F, corresponding to "the first gain", which has the characteristic that the higher a frequency of the error signal, the smaller the gain, and the gain G_M, corresponding to "the second gain", which has the characteristic that the larger amplitude of the error signal, the larger the gain. This makes it possible to optimize the response characteristics of the control system by achieving both high-speed control to follow the magnetic field setting

changes at high speed and internal noise suppression to absorb variation in the command value/detected value caused by internal noise.

In the control device for the magnetic field generator **30** of one or more embodiments, the gain (G_M) is set in accordance with the command value response required for the command value of the reference value signal, the output value response required for the variation in the output of the magnetic field generator **30**, and the detected value response required for the variation in the detection value of the magnetic field sensor **40**. This makes it possible to optimize the response characteristics of the control system by achieving both high-speed control to follow the magnetic field setting changes at high speed and internal noise suppression to absorb variation in the command value/detected value caused by internal noise.

In the control device for the magnetic field generator **30** of one or more embodiments, the gain (G_M) has the characteristic that the gain increases continuously with increasing the amplitude. For example, in a system control different from one or more embodiments, there is a control in which the gain is switched by a switch, but the gain characteristics in such a control cannot maintain the continuity of the output against input variation. However, the gain characteristics in such control cannot maintain continuity of the output in response to input variation. On the other hand, in one or more embodiments, the gain characteristics change smoothly, so the continuity of the output can be maintained in response to input variation.

The test apparatus of one or more embodiments includes the magnetic field generator **30** that includes the coil and a core, and outputs the magnetic field to the electronic component under test, and the magnetic field sensors **40** that detects the magnetic field that detects the magnetic field. This makes it possible to optimize the response characteristics of the control system by achieving both high-speed control to follow the magnetic field setting changes at high speed and internal noise suppression to absorb variation in the command value/detected value caused by internal noise.

The magnetic field control method of one or more embodiments includes: a step of obtaining, by a feedback control, the detected value of a magnetic field sensor **40**; a step of obtaining a command value of the magnetic field generated by a magnetic field generator **30**; a step of generating the error signal in accordance with the error between the command value and the detected value; and a step of outputting the control signal amplified by the control gain against the error. The control gain includes the gain G_F which has the characteristic that the higher a frequency of the error signal, the smaller the gain, and the gain G_M which has the characteristic that the larger amplitude of the error signal, the larger the gain. This makes it possible to optimize the response characteristics of the control system by achieving both high-speed control to follow the magnetic field setting changes at high speed and internal noise suppression to absorb variation in the command value/detected value caused by internal noise.

Although the disclosure has been described with respect to only a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that various other embodiments may be devised without departing from the scope of the present invention. Accordingly, the scope of the invention should be limited only by the attached claims.

EXPLANATIONS OF LETTERS OR NUMERALS

10 Electronic component under test (DUT)
20 Socket

30 Magnetic field generator
31 Core
32 Main coil
33 Correction coil
40 Magnetic field sensor
50 Controller
60 Magnetic field control circuit
100 Test apparatus

What is claimed is:

1. A control device that controls a magnetic field generated by a magnetic field generator, the control device comprising:
  a magnetic field controller that controls the magnetic field generator based on a detected value of the magnetic field by a magnetic field sensor,
  wherein the magnetic field controller receives:
    a command value of the magnetic field generated by the magnetic field generator, and
    the detected value by the magnetic field sensor that is fed back to the magnetic field controller,
  the magnetic field controller generates an error signal based on an error between the command value and the detected value and outputs to the magnetic field generator a control signal amplified by a control gain against the error signal,
  the control gain includes:
    a first gain that becomes smaller as a frequency of the error signal gets higher; and
    a second gain that gets larger as an amplitude of the error signal gets larger.

2. The control device according to claim **1**, wherein the second gain is based on a command value response required for variation in the command value, an output value response required for variation in an output of the magnetic field generator, and a detected value response required for variation in the detection value of the magnetic sensor.

3. The control device according to claim **1**, wherein the second gain increases continuously with the amplitude increasing.

4. A test apparatus that tests an electronic component under test, the test apparatus comprising:
  a magnetic field generator that comprises a coil and a core and outputs a magnetic field to the electronic component under test;
  a magnetic field sensor that detects the magnetic field; and
  a magnetic field controller that controls the magnetic field generator based on a detected value of the magnetic field by the magnetic field sensor;
  wherein the magnetic field controller receives:
    a command value of the magnetic field generated by the magnetic field generator, and
    the detected value by the magnetic field sensor that is fed back to the magnetic field controller,
  the magnetic field controller generates an error signal based on an error between the command value and the detected value and outputs to the magnetic field generator a control signal amplified by a control gain against the error signal,
  the control gain includes:
    a first gain that becomes smaller as a frequency of the error signal gets higher; and
    a second gain that gets larger as an amplitude of the error signal gets larger.

5. A method for controlling a magnetic field generated by a magnetic field generator, the method comprising:

obtaining, by a feedback control, a detected value of the magnetic field by a magnetic field sensor;

obtaining a command value of the magnetic field generated by the magnetic field generator;

generating an error signal based on an error between the command value and the detected value; and

outputting to the magnetic field generator a control signal amplified by a control gain against the error signal, wherein

the control gain includes:

a first gain that becomes smaller as a frequency of the error signal gets higher; and

a second gain that gets larger as an amplitude of the error signal gets larger.

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